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Identification of characteristic basin descriptors for flood frequency curves behaviour

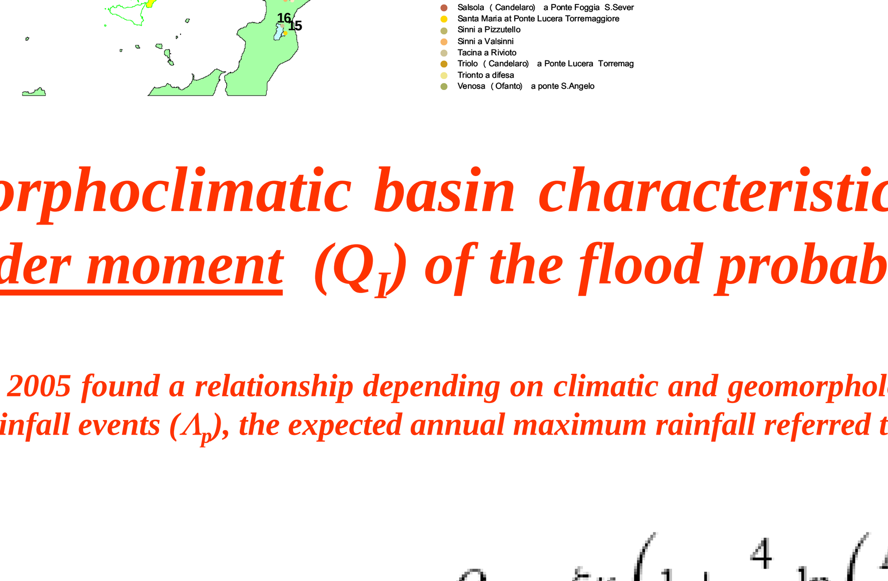
A. Gioia (1), V. Iacobellis (1), S. Manfreda (2), M. Fiorentino (2)

Dipartimento di Ingegneria delle Acque e di Chimica (DIAC), Politecnico di Bari, Italy. (2) Dipartimento di Ingegneria e Fisica dell'Ambiente (DIFA), University of Basilicata, Italy*e-mail: a.gioia@poliba.it*

ABSTRACT

The estimation of flood frequency curves in ungauged basins is a crucial issue for practical and technical applications. In this field, a significant contribution may come from the use of theoretically derived probability distributions where parameters have a physical meaning that may be related to the basin features. The challenge is to define synthetic basin descriptors able to interpret and classify the main characteristics of flood probability distribution. In the present work, a variant of the theoretical model proposed by Iacobellis and Fiorentino [2000] has been adopted with the purpose to describe and classify the model according to the hydrological processes underlying the flood generation mechanisms. The model has been modified including a two flood generation mechanisms accounting for the nonlinear behaviour of soil response. Climatic and physiographic basin features are investigated as possible basin descriptors in order to predict the statistical moments of the flood probability distributions. The analyses are carried out over a wide area of Southern Italy that includes gauged basins belonging to the Regions of Basilicata, Calabria, Puglia and Campania. Results allow a better understanding the role played by the climate, soil permeability and basin morphology in flood statistics.

Climatic and physiographic basin features of 33 southern Italy basins are investigated as possible basin descriptors in order to predict the statistical moments of the flood probability distributions.



	Nid_	r	I	A (km2)	urb	CN	ψ	Sm	Crunoff	Cv [Itop]	Q_1 (m³/s)
Noce at La Calda	12	0.08	1.58	43.61	0.00	63.59	0.21	0.21	0.34	0.22	30.68
Lao at Piè di Borgo	13	0.3	1.16	279.78	0.09	71.00	0.78	0.19	0.28	0.23	214.31
Amato at Marino	14	0.3	0.86	115.00	0.00	55.74	0.95	0.15	0.29	0.22	79.19
Alaco at Mammone	15	0.06	1.66	14.95	0.00	36.39	1.00	0.10	0.13	0.18	13.61
Ancinale at Razzona	16	0.11	1.34	116.43	0.00	38.63	1.00	0.10	0.15	0.21	82.35
Melito at Olivella	17	0.07	0.72	41.27	0.00	51.22	0.93	0.16	0.21	0.24	17.18
Alli at Orso	18	0.05	1.26	46.00	4.29	35.78	0.98	0.15	0.18	0.22	16.66
Tacina at Rivioto	19	0.25	1.43	77.00	0.00	36.93	0.97	0.17	0.12	0.22	81.16
Trionto at Difesa	20	0.04	0.90	31.50	0.00	54.83	0.99	0.07	0.22	0.18	8.73
Esaro at La Musica	21	0.45	0.77	532.00	0.00	64.30	0.93	0.17	0.27	0.25	328.84
Coscile at Camerata	22	0.1	0.65	303.00	0.40	68.14	0.79	0.20	0.28	0.24	80.34
Crato at Conca	23	0.13	0.61	1332.00	0.88	57.23	0.89	0.14	0.26	0.25	441.42
Corace at Grascio	24	0.28	0.90	178.00	0.00	53.59	0.94	0.17	0.24	0.24	151.65
Santa Maria at Ponte Lucera Torremaggior	25	0.15	-0.28	58.00	0.00	86.13	0.99	0.05	0.46	0.22	18.44
Triolo at Ponte Lucera Torremaggiore	26	0.2	-0.25	56.00	0.00	85.69	0.98	0.06	0.49	0.21	35.44
Salsola at Ponte Foggia San Severo	27	0.12	-0.27	455.00	0.00	82.47	0.96	0.05	0.46	0.23	76.14
Casanova at Ponte Lucera Motta	28	0.18	-0.14	57.00	0.00	81.12	0.92	0.09	0.51	0.22	26.53
Celone at Ponte Foggia San Severo	29	0.08	-0.24	233.00	0.00	83.29	0.98	0.03	0.48	0.22	45.70
Celone at San Vincenzo	30	0.11	-0.06	92.00	0.00	83.16	0.96	0.10	0.50	0.23	31.82
Cervaro at Incoronata	31	0.54	-0.19	539.00	0.09	76.68	0.55	0.08	0.63	0.23	215.80
Carapelle at Carapelle	32	0.45	-0.23	715.00	0.06	81.20	0.59	0.07	0.58	0.23	283.74
Venosa at Ponte Sant' Angelo	33	0.14	-0.17	263.00	0.27	78.38	0.85	0.07	0.52	0.21	55.84
Arcidiaconata at Ponte Rapolla Lavello	34	0.2	-0.04	124.00	0.00	52.76	0.83	0.12	0.49	0.21	45.06
Ofanto at Rocchetta Sant' Antonio	35	0.7	0.16	1111.00	0.37	71.85	0.25	0.13	0.52	0.22	456.62
Atella at Ponte sotto Atella	36	0.13	0.17	176.00	0.00	72.27	0.45	0.11	0.52	0.20	61.27
Bradano at Ponte Colonna	37	0.35	-0.08	462.00	0.00	75.66	0.46	0.10	0.55	0.22	201.56
Bradano at San Giuliano	38	0.36	-0.17	1657.00	0.00	80.43	0.48	0.09	0.56	0.23	507.06
Basento at Pignola	39	0.25	0.70	42.00	0.15	74.95	0.63	0.15	0.40	0.21	34.86
Basento at Gallipoli	40	0.26	0.28	853.00	0.36	70.28	0.40	0.16	0.52	0.22	352.61
Basento at Menzena	41	0.18	0.08	1382.00	0.00	76.46	0.41	0.12	0.51	0.24	400.63
Agri at Tarangelo	42	0.26	0.47	511.00	0.53	74.67	0.63	0.16	0.46	0.24	189.24
Sinni at Valsinni	43	0.19	0.57	1140.00	0.62	72.09	0.41	0.16	0.40	0.23	554.91
Sinni at Pizzutello	44	0.27	1.26	232.00	0.82	76.96	0.30	0.20	0.44	0.22	232.63

Geomorphoclimatic basin characteristics may be possible basin descriptors for the first order moment (Q_I) of the flood probability distribution.

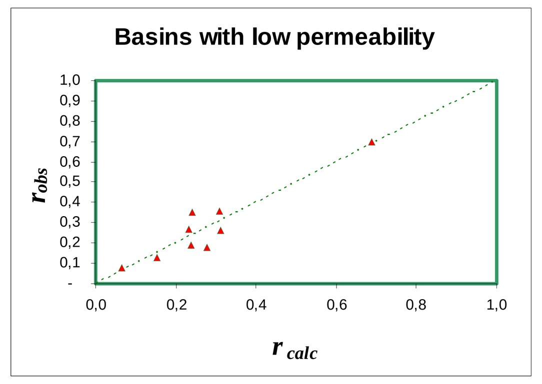
Gioia et al. 2005 found a relationship depending on climatic and geomorphologic river characteristics through the routing factor ξ, mean annual number of flood (Λ_q) and rainfall events (Λ_p), the expected annual maximum rainfall referred to the expected value of contributing area rA, the ratio r and basin area A.

$$Q_I = \xi\kappa\left(1+\frac{4}{15}\ln\left(\frac{\Lambda_q}{\Lambda_p}\right)\right) I_{rA}\, r\, A + q_o$$

A multiple linear regression between "r" and soil permeability Ψ, variation coefficient of the topografic index Cv[Itop] (Beven and Kirkby, 1979), climate climatic index I (Thornthwaite, 1948), percentage of urban area (urb), Curve Number (CN), runoff coefficient (C_{runoff}) and mean slope S_m were found for basins with different permeability.

$$\boldsymbol{R}^2 = 0{,}88$$

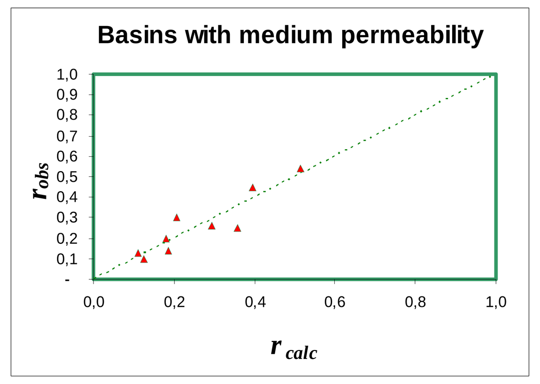
$$r = -0{,}43\, I - 2{,}15\,\psi + 0{,}27\, urb + 1{,}19$$



$$0 \le \psi \le 0{,}50$$

$$\boldsymbol{R}^2 = 0{,}84$$

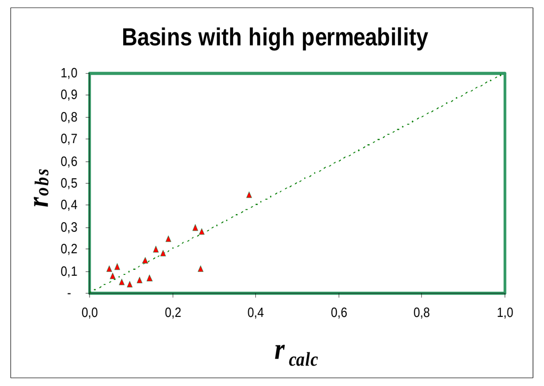
$$r = 1{,}87\, C_{runoff} + 0{,}29\, I + 4{,}44\, Cv[I_{top}] - 1{,}65$$



$$0{,}50 \le \psi \le 0{,}9$$

$$\boldsymbol{R}^2 = 0{,}69$$

$$r = 1{,}95 S_m + 0{,}02 CN + 0{,}36 I + 1{,}25$$



$$0{,}90 \le \psi \le 1$$

The Theoretical Model for Probability Distribution of Floods

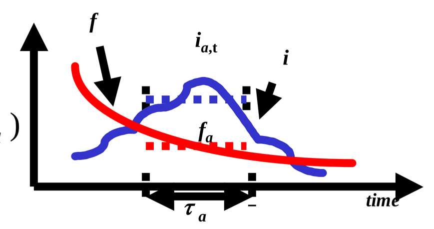
The theoretical model by *Iacobellis and Fiorentino* (2000) is based on the hypothesis that the **peak of direct streamflow *Q*** is the product among two random variables: **runoff per unit of contributing area u_a** and portion of the basin area that contributes to direct runoff. In this model, the peak discharge per unit contributing area u_a, is linearly related (by means of a constant **routing factor** ξ) to the **time average effective rainfall intensity, $i_{a,\tau}$,** fallen **on the contributing part of the basin *a***, and occurring in a duration equal to a characteristic **response time τ_a** of the same contributing area *a*.

The hypothesis.

$$Q = u_a \cdot a$$

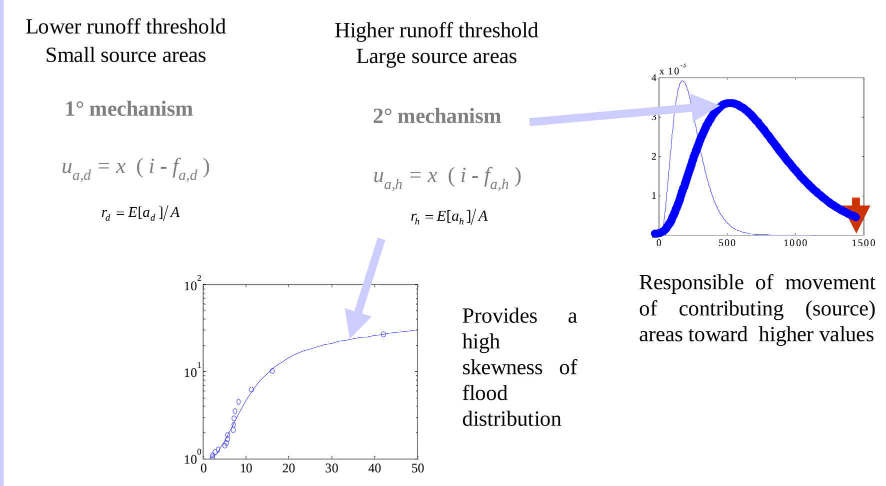
(threshold runoff mechanism) $u_a = \xi\,(i_{a,\tau} - f_a)$

$E[i_{a,t}] = i_1(a)^{-\varepsilon}$



The infiltration $f_a = f_1(a)^{-\varepsilon'}$ $\tau_a = \tau_1\, a^{\nu}$

Hp: Non linearity effect in the flood generation process may be accounted for by two different (threshold) mechanisms of runoff generation



A Two Component annual maximum CDF

The peak flow cumulative distr'n function:

$$G_{Q,d}(q) = \int_0^A \int_0^{q/a} g(u\,|\,a_d)\, g(a_d)\, du\, da_d \qquad G_{Q,h}(q) = \int_0^A \int_0^{q/a} g(u\,|\,a_h)\, g(a_h)\, du\, da_h$$

Under the hypotesis of compound Poisson processes of independent peak flows with rate Λ_q, the annual maxima flood cumulative distribution is:

$$F_{Q_p}(Q_{max}) = \exp\{-\Lambda_d[1-G_{Q,d}(Q_{max})] - \Lambda_h[1-G_{Q,h}(Q_{max})]\}$$

$$\Lambda_q \approx \Lambda_d = \Lambda_p \exp\left(-\frac{f_{A,d}^{\ k}}{E[i_{A,\tau}^k]}\right) \qquad \Lambda_h = \Lambda_p \exp\left(-\frac{f_{A,h}^{\ k}}{E[i_{A,\tau}^k]}\right) \qquad \Lambda_q = \Lambda_d + \Lambda_h$$

Possible simplification: Under the hypothesis of EV1 rainfall distribution, the weibull distribution is replaced by an exponential distribution.

$$F_{Q_p}(q_p) = \exp\left\{-\Lambda_d\left[\int_0^A g(a)\exp\left(-\frac{((q_p-q_b)/(\xi a))}{(i_1 a^{-\varepsilon})}\right)da\right] - \Lambda_h\left[\int_0^A g(a)\exp\left(-\frac{((q_p-q_b)/(\xi a))}{(i_1 a^{-\varepsilon})}\right)da\right]\right\}$$

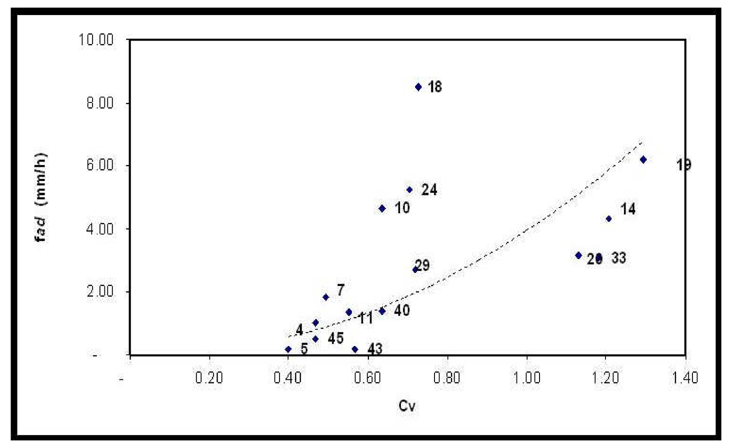
$$g(a) = \frac{1}{\alpha\Gamma(\beta)}\left(\frac{a}{\alpha}\right)^{\beta-1} exp\left(-\frac{a}{\alpha}\right) + \delta(a-A)P_A \qquad \alpha_d = r_d A/\beta, \qquad \alpha_h = r_h A/\beta$$

$$\Lambda_q \approx \Lambda_d = \Lambda_p \exp\left(-\frac{f_{A,d}}{E[i_{A,\tau}]}\right) \qquad \Lambda_h = \Lambda_p \exp\left(-\frac{f_{A,h}}{E[i_{A,\tau}]}\right)$$

Three unknown parameters : r_d , r_h, $f_{A,h}$

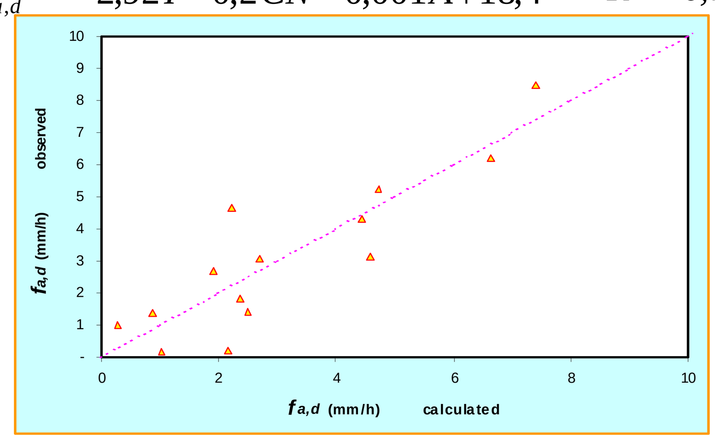
River basins with non linear behaviour of soil response

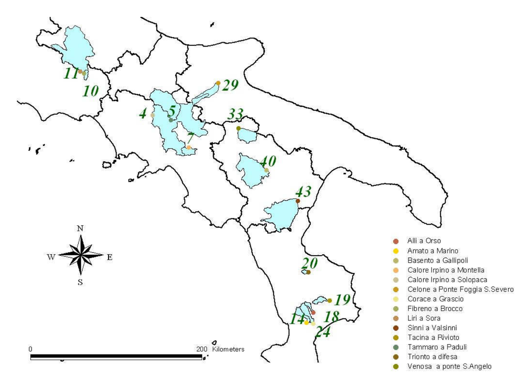
The Coefficient of Variation (Cv) is related to the infiltration threshold of the 1° mechanism ($f_{a,d}$)



Climate, landuse, soil permeability and basin morphology (by means of the Curve Number coefficient) control this parameter by means of amultiple linear regression:

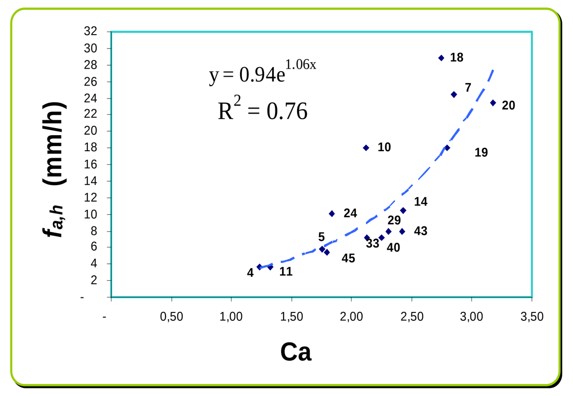
$$f_{a,d} = -2{,}92 I - 0{,}2 CN - 0{,}001 A + 18{,}4 \qquad R^2 = 0{,}77$$



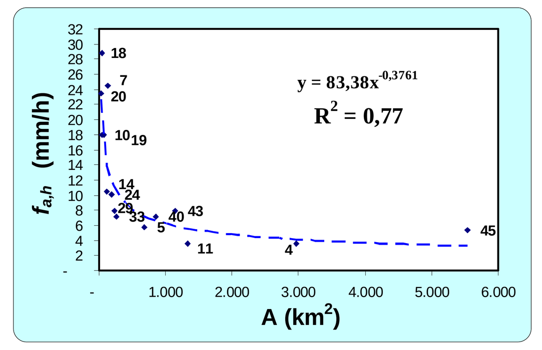


	N_{id}	A (km²)	I	ψ	CN	$f_{a,d}$ (mm/h)	$f_{a,h}$ (mm/h)	Ca	Cv
Celone at Ponte Foggia San Severo	29	233	-0,24	0,98	82,47	2,70	7,92	2,31	0,72
Venosa at Ponte Sant' Angelo	33	263	-0,17	0,85	76,68	3,06	7,20	2,13	1,18
Basento at Gallipoli	40	853	0,28	0,40	80,43	1,40	7,20	2,25	0,64
Sinni at Valsinni	43	1140	0,57	0,41	76,46	0,17	7,92	2,42	0,57
Trionto at Difesa	20	32	0,90	0,99	35,78	3,13	23,40	3,18	1,13
Tacina at Rivioto	19	79	1,43	0,97	51,22	6,19	18,00	2,79	1,29
Alli at orso	18	46	1,26	0,98	38,63	8,50	28,80	2,74	0,73
Corace at Grascio	24	182	0,90	0,94	68,14	5,26	10,08	1,83	0,70
Amato at Marino	14	113	0,86	0,95	63,59	4,32	10,44	2,43	1,21
Liri at Sora	11	1329	0,74	0,66	67,69	1,37	3,60	1,32	0,55
Fibreno at Brocco	10	48	0,77	0,71	62,75	4,64	18,00	2,12	0,64
Calore Irpino at Montella	7	123	1,18	0,63	72,09	1,84	24,48	2,85	0,49
Tammaro at Paduli	5	673	0,33	0,87	67,64	0,19	5,76	1,75	0,40
Calore Irpino at Solopaca	4	2966	0,32	0,85	68,25	1,01	3,60	1,24	0,47

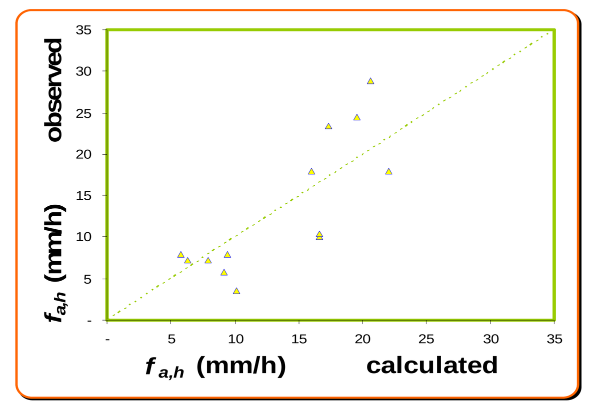
The skewness (Ca) is controlled by the infiltration threshold of the 2° mechanism ($f_{a,h}$)



This parameter is mainly related to Basin Area



A multiple linear regression was found between $f_{a,h}$, Basin Area A and Thornthwaite climatic index I:



$$f_{a,h} = 9{,}35\,\boldsymbol{I} - 0{,}004\,\boldsymbol{A} + 9$$

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